State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

DUNGENESS CRAB RESEARCH PROGRAM

Report for the Year 1977

by

Program Staff

Harold G. Orcutt, Compiler

MARINE RESOURCES

Administrative Report No. 77-21

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DUNGENESS CRAB RESEARCH PROGRAM[1/]

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ABSTRACT

All 1977 year class larval stages, except fifth zoeae, occurred in the study area. California Cooperative Oceanic Fisheries Investigations (CalCOFI) plankton samples of February 1950, taken 67 and 111 miles off San Francisco, contained fifth stage zoeae and megalopae. Megalopae and early post-larval forms were found inshore and in the San Francisco-San Pablo Bay complex in the spring. The zoeae drifted offshore and later appeared inshore or were replaced by megalopae from without the study area. An invasion of warm water into the Gulf of the Farallones in late January and February may have accelerated development to the first crab stage, and zooplankters of oceanic and warm waters were found in association with crab zoeae. Eighty percent of a strong 1977 year class entered the Bay complex.

Regression analyses were computer run comparing crab landings to quarterly oceanographic parameters coinciding with specific life history phenomena. Sea levels, indicators of ocean currents, are highly correlated to landings and also appear to be partly responsible for some high coefficient of determination values in multiple regressions. Crabs held at controlled temperatures revealed egg development, spawning, and feeding rates are affected by increased temperature. Crab mating success was 90% in the San Francisco area, and small samples from Eureka revealed similar success. Smaller ovaries in central California crabs prompt study of the possibility of lowered reproductive potential.

Background levels of cadmium in juvenile crabs and water in which they were reared at the Marine Culture Laboratory were determined prior to beginning bioassays. Range-finding bioassays determined 10 mg/l of cadmium a mid-point for full-scale bioassays. Higher levels of petroleum hydrocarbons in the larger juvenile crabs from San Francisco Bay suggest crabs there acquire large hydrocarbon burdens.

Satisfactory methods of rearing zoeal stages of crab were developed, and refinement of culture techniques was made for megalopae and post-larval instars.

1/ Marine Resources Administrative Report 77-21, December 1977.

2/ Operations Research Branch, 411 Burgess Dr., Menlo Park, CA. 94025

FOREWORD

The State Legislature in 1974, by Senate Bill 1606, directed the Department of Fish and Game to conduct an investigation into the causes of the long-term decline in the central California Dungeness crab resource.

This report is the fourth in the series of Marine Resources Administrative Reports which presents the Department's Dungeness Crab Research Program and progress of its investigations. Marine Resources Administrative Report 75-8 was the research proposal for the program. It presented the central California crab problem, objectives of the new program, research design, work plans for the 4-year study, and an outline of preliminary research activities.

For details of organization, research methods, and prior results, the reader is referred to the research proposal and to previous annual reports. The program progress report of 1975 was printed as Marine Resources Administrative Report 75-12. Marine Resources Administrative Report 76-15 discussed changes in operations and results of our work in 1976. This year's progress report is similar in format to the 1976 report.

The final report to the Governor and Legislature in September 1979 will include the findings of the 4-year program together with recommendations for some actions to protect the resource and increase the abundance of crabs in State waters.

H. G. Orcutt

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INTRODUCTION

by

Harold G. Orcutt[3/]

The Problem

In the 1976-77 season the resource of central California Dungeness crab, *Cancer magister*, remained at a depressed level, while northern California had the highest seasonal harvest in the history of the fishery (Figure 1, Table 1).

The high landings in 1975-76 and the record 1976-77 harvest of 25.6 million lb (11,612 MT) of crabs off northern California overshadowed the small, but increased landings of 612,000 lb (277 MT) off central California during the 1976-77 season.

The Objective

The objective of the Dungeness Crab Research Program is to determine factors causing the decline and continued low levels of central California's Dungeness crab resource and to make management recommendations to protect and increase the resource.

Background

The Dungeness crab fisheries in California are concentrated off the central (San Francisco-Bodega) and northern (Crescent City-Eureka-Fort Bragg) parts of the state. There is less fishing effort for crabs at Monterey and Morro Bay.

Catches of Dungeness crabs off California are landed in four principal areas of the northern and central portions of the state. Landings at the

3/ Operations Research Branch, 411 Burgess Dr., Menlo Park, CA. 94025

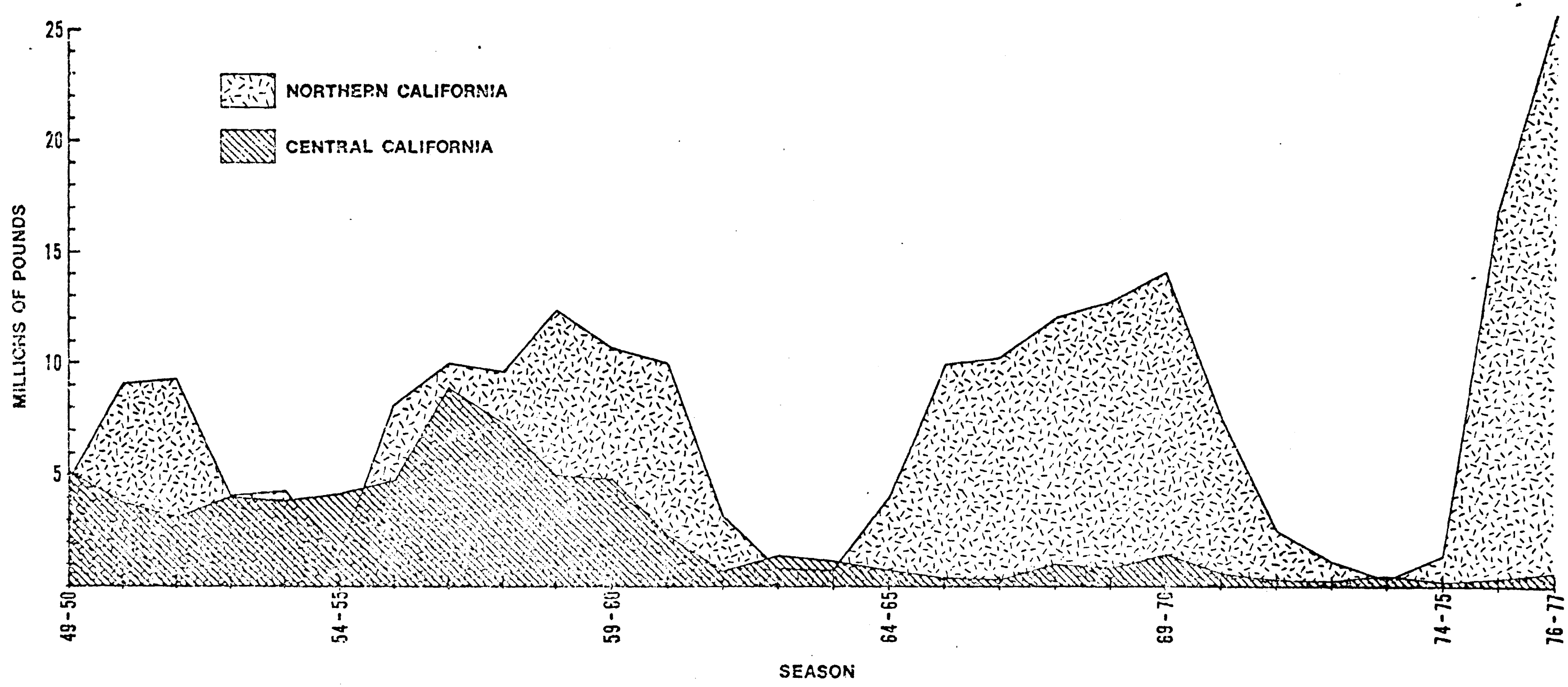

FIGURE 1. Dungeness crab landings of northern and central California by seasons since 1949.

TABLE 1. Dungeness Crab Landings by Season (Pounds)

Season	Eureka, Crescent City, and Ft. Bragg	Bodega Bay and San Francisco Area	Monterey Bay Area	Avila and Morro Bay	Total
1915-16	107,016	454,584	294,048	...	855,648
1916-17	289,464	1,594,344	286,608	...	2,170,416
1917-18	99,552	2,125,920	38,904	...	2,264,376
1918-19	55,032	927,264	13,200	72	995,568
1919-20	71,184	1,364,352	11,928	...	1,447,464
1920-21	66,792	661,944	3,600	...	732,336
1921-22	141,312	830,904	2,400	...	974,616
1922-23	263,328	628,464	5,088	...	896,880
1923-24	165,792	1,136,232	12,792	...	1,314,816
1924-25	183,768	2,973,576	100,536	...	3,257,880
1925-26	207,960	2,752,464	49,656	...	3,010,080
1926-27	177,792	2,738,256	147,264	...	3,063,312
1927-28	95,928	2,890,344	558,312	...	3,544,584
1928-29	62,880	1,851,024	69,600	...	1,983,504
1929-30	99,168	1,879,800	11,832	...	1,990,800
1930-31	110,896	2,173,009	515	...	2,284,420
1931-32	113,878	2,229,031	5,710	...	2,348,619
1932-33	126,428	2,760,944	173,726	...	3,061,098
1933-34	113,775	3,352,224	183,342	...	3,649,341
1934-35	152,366	3,253,188	114,308	...	3,519,862
1935-36	231,684	2,563,012	4,380	...	2,799,076
1936-37	180,504	1,224,245	6,670	44	1,411,463
1937-38	528,108	3,072,444	37,120	...	3,637,672
1938-39	1,993,633	3,641,412	498,200	...	6,133,245
1939-40	1,299,142	3,547,048	43,024	...	4,889,214
1940-41	477,718	4,259,916	38,658	...	4,776,292
1941-42	688,386	1,773,704	72,248	...	2,534,338
1942-43	232,372	1,651,174	70,060	...	1,953,606
1943-44	340,400	2,588,731	107,667	...	3,036,798
1944-45	1,340,717	2,171,190	98,118	565	3,610,590
1945-46	5,812,574	3,420,225	27,549	450	9,260,798
1946-47	5,653,754	3,694,312	67,721	...	9,415,787
1947-48	5,619,089	4,863,747	66,555	4,617	10,554,008
1948-49	6,764,248	5,398,738	28,464	27,401	12,218,851
1949-50	4,772,314	5,116,522	23,257	155,864	10,067,957
1950-51	9,066,177	3,793,707	14,639	433,706	13,308,229
1951-52	9,292,763	3,204,755	14,432	97,458	12,609,408
1952-53	4,118,754	4,114,780	13,046	30,345	8,276,925
1953-54	4,309,220	3,888,782	10,634	57,113	8,265,749
1954-55	1,524,511	4,238,072	9,903	81,163	5,853,649

TABLE 1. (continued)

Season	Eureka, Crescent City, and Ft. Bragg	Bodega Bay and San Francisco Area	Monterey Bay Area	Avila and Morro Bay	Total
1955-56	8,063,261	4,771,613	11,331	236,858	13,083,113
1956-57	9,980,254	8,919,172	66,777	313,202	19,279,405
1957-58	9,610,277	7,391,488	130,070	155,801	17,287,636
1958-59	12,377,569	5,014,214	105,184	288,706	17,785,673
1959-60	10,728,132	4,784,138	94,932	257,983	15,865,185
1960-61	10,042,841	2,303,604	32,999	66,593	12,446,037
1961-62	3,251,318	710,350	15,092	9,929	3,986,689
1962-63	900,733	1,429,780	8,616	2,559	2,341,688
1963-64	814,997	1,171,304	9,915	2,119	1,998,335
1964-65	3,978,997	760,402	5,774	4,393	4,749,566
1965-66	9,985,618	446,894	4,894	4,371	10,441,777
1966-67	10,299,169	396,467	2,524	7,260	10,705,420
1967-68	12,142,853	1,013,589	757	2,126	13,159,325
1968-69	12,848,716	833,164	3,331	93	13,685,304
1969-70	14,111,926	1,477,611	1,661	1,132	15,592,330
1970-71	7,838,049	657,298	640	4,575	8,500,562
1971-72	2,541,969	319,175	303	14,115	2,875,562
1972-73	1,154,002	291,641	394	53,581	1,499,618
1973-74	353,117	402,700	1,974	121,462	879,253
1974-75	1,458,871	230,976	2,378	123,434	1,815,659
1975-76	17,056,337	340,945	1,683	12,800	17,411,765
1976-77	25,600,000	612,000			

northern ports of Crescent City, Eureka and Fort Bragg (Table 1) represent the bulk of the catch and follow the cyclic pattern of crab abundance which occurs in the harvested crab population (Figure 1). This pattern of fluctuation is similar for Dungeness crab fisheries off Oregon and Washington. Landings of crabs in northern California, which had a mean annual yield of 9.2 million lb (4,182 MT) per season from 1955-56 through 1969-70, plummeted from a high of over 14 million lb (6,364 MT) in 1969-70, to 7.8 million lb (3,545 MT) in 1970-71, 2.5 million lb (1,136 MT) in 1971-72, 1.2 million lb (545 MT) in 1972-73 and to a record low of 360,000 lb (164 MT) in 1973-74. During the 1974-75 season 1.5 million lb (681 MT) were landed, indicating another upswing of the cyclic pattern which went to slightly over 17 million lb (7,727 MT) in 1975-76. Research cruises in 1976 revealed a relatively strong reserve of recruits in the population to support continuation of good landings in the 1976-77 season. The harvest for 1976-77 was a record high of nearly 25 million lb (11,612 MT). This upswing indicates a critical difference in crab survival between the extremely cyclic population of northern California and the low-yielding resource of the San Francisco region.

The central California Dungeness crab resource has yielded harvestable crabs at drastically low levels for 16 seasons in comparison to the long-term average of previous seasons (Figure 1). This, as yet, unexplained decline is of serious concern because it indicates a continuing situation rather than a fluctuation. The long-term mean annual yield for San Francisco crab season landings had been 4.8 million lb (2,182 MT) from 1945 to 1960. The area's crab landings reached an all-time peak of 8.9 million lb (4,045 MT) during the 1956-57 season and then declined at the rate of approximately

2 million lb (909 MT) each season until the 1961-62 season when only 710,112 lb (323 MT) were landed. Low landings have occurred each season since then. A slight increase was seen during the 1962-63 and 1963-64 seasons when 1.3 and 1.2 million lb (590 and 545 MT) were landed, respectively, and again in 1969-70 with a high of 1.5 million lb (682 MT). These variations are the only indications of a tendency to follow a cyclic upswing such as that occurring to the north. The 1972-73 season's take was 291,551 lb (133 MT). The 1973-74 season harvest was only 402,700 lb (183 MT) and the totals of 230,976 lb (105 MT) for 1974-75, and 340,945 lb (155 MT) for 1975-76 are the poorest in the history of the fishery. The take of crabs from central California waters in the 1976-77 season totaled 612,000 lb (278 MT). That increase was encouraging but the outlook for 1977-78 is not as good. Early 1977-78 season landings indicate the yield will not be substantially more than those of recent seasons. Also, research cruise data for this area do not indicate sufficient recruits for a continued upswing in the immediate future, but a relatively strong 1977 year class may result in improvement in the 1980-81 season.

South of the problem area, combined landings of Monterey and Morro Bay have never exceeded 600,000 lb (272 MT). The long-term average (1950-51 to 1974-75) is 117,595 lb (53 MT). This fishery is at the southern limit of commercial abundance of crabs; hence low abundance and wide fluctuations are to be expected. During the seasons 1970-71 through 1975-76, landings ranged from 5,215 to 125,812 lb (2 to 57 MT).

Program Development

Senate Bill 1606 of 1974 directed the Department of Fish and Game to conduct an investigation into the factors responsible for the decline of

Dungeness crab harvests in central California. The law also provided that a special privilege tax of $0.0185 per pound of crab taken be used only for crab research and management. The intent of S.B. 1606 was to raise $500,000 to fund the investigation. The cumulative total of tax collected surpassed $500,000 in 1977, and the tax was terminated by the passage of Assembly Bill 858.

The Dungeness Crab Research Program proposal for the 4-year study included six technical positions. However, fiscal constraints allowed only five positions to be established; the funds generated by the tax on crab landings were extremely low when the program began. The income from the tax on crabs landed in the 1975-76 and 1976-77 seasons increased significantly, and budgets were drawn up to use some of those funds to support most of the research program in fiscal years 1977-78 ($175,289) and 1978-79 ($214,000). Over and above the 1978-79 budget, $100,000 has been designated for studies of contaminants in the environment. These studies relate to the effects of chlorinated effluents, petroleum hydrocarbons, and heavy metals on crabs.

Although the position for a sixth biologist was never filled, the staff of the Dungeness Crab Research Program anticipates that the objectives of the program will be met, but this necessitates less qualitative and quantitative detail in field sampling and laboratory examinations.

Substantial assistance has come to the Dungeness Crab Research Program from several other Fish and Game units. Staff and field operations of Operations Research Branch have been a major source of support. Biometrics sections have given assistance on data storage and analyses, and the Marine Culture Laboratory has devoted much time and use of facilities for crab studies. Marine Resources Region (MRR) biologists have assisted in field work and provision of equipment. MRR vessel operations have supported our many research cruises, and the Marine Bioassay Laboratory facilities have been made available for studies. The Technical Information Center provided library assistance. The Bay-Delta Fishery Project and the Anadromous Fisheries Branch have provided research vessels and crew for many cruises in the San Francisco Bay area. The Water Pollution Control Laboratory of Environmental Services Branch has assisted in determining toxic element burdens in crabs, and the Department's Pesticide Laboratory determined levels of pesticides and polychlorinated biphenyls in crab tissues.

Meetings and Cooperative Research Activities

During 1977 the Dungeness Crab Research Program participated in presentations and discussions of the Dungeness Crab Species Management Plan for Extended Jurisdiction. The management plan prepared by the Program in 1976 includes information on status of the resource, a description of the fishery, and recommendations for management. The plan was reviewed by the Department in July and presented to the Fish and Game Commission in August. The plan is a contribution to the Department's effort to prepare species management plans for the Pacific Management Council.

Scientists at the Bodega Marine Laboratory are making comprehensive studies of the parasitic nemertean worms which infest and feed upon eggs carried by female crabs, techniques for rearing crab larvae in vertical culture tubes, and statistical models to explain the wide fluctuations in crab abundance off northern California.

During the year program staff members met with various groups to discuss the research program and progress of the various project activities. The principal meetings were:

San Francisco Bay and Estuarine Society

California Fish and Game Commission

Pacific Marine Fisheries Commission Advisors

San Francisco Bay and Estuary Advisory Committee

University of California Bodega Marine Laboratory

American Association for the Advancement of Science

CRAB CRITICAL STAGE PROJECT STUDIES

by

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The project concentrated on fulfilling two major objectives in 1977. They were as follows:

1. Determination of the distribution and relative abundance of Dungeness crab zoeae, megalopae, and early post-larval instars.
2. Determination of predators and their effects on crab population numbers.

Some additional data were collected regarding growth rates of juvenile crabs in Bay waters. A manuscript describing these growth rates is near completion.

Because of data storage delays and a changeover of personnel in late 1976, the 1976 annual report was incomplete regarding zooplankton and stomach content analysis. Therefore, the data and determinations reported herein include some material from 1976 as well as most from 1977.

We have described our methodologies and gear in previous annual reports (Orcutt et al. 1975a, 1975b, 1976) but will define such items again when changes or circumstances warrant it.

Distribution and Relative Abundance

Procedures

Five major cruises were conducted in the principal study area (Figures 2 and 3) to investigate the 1977 year class of *Cancer magister* and were

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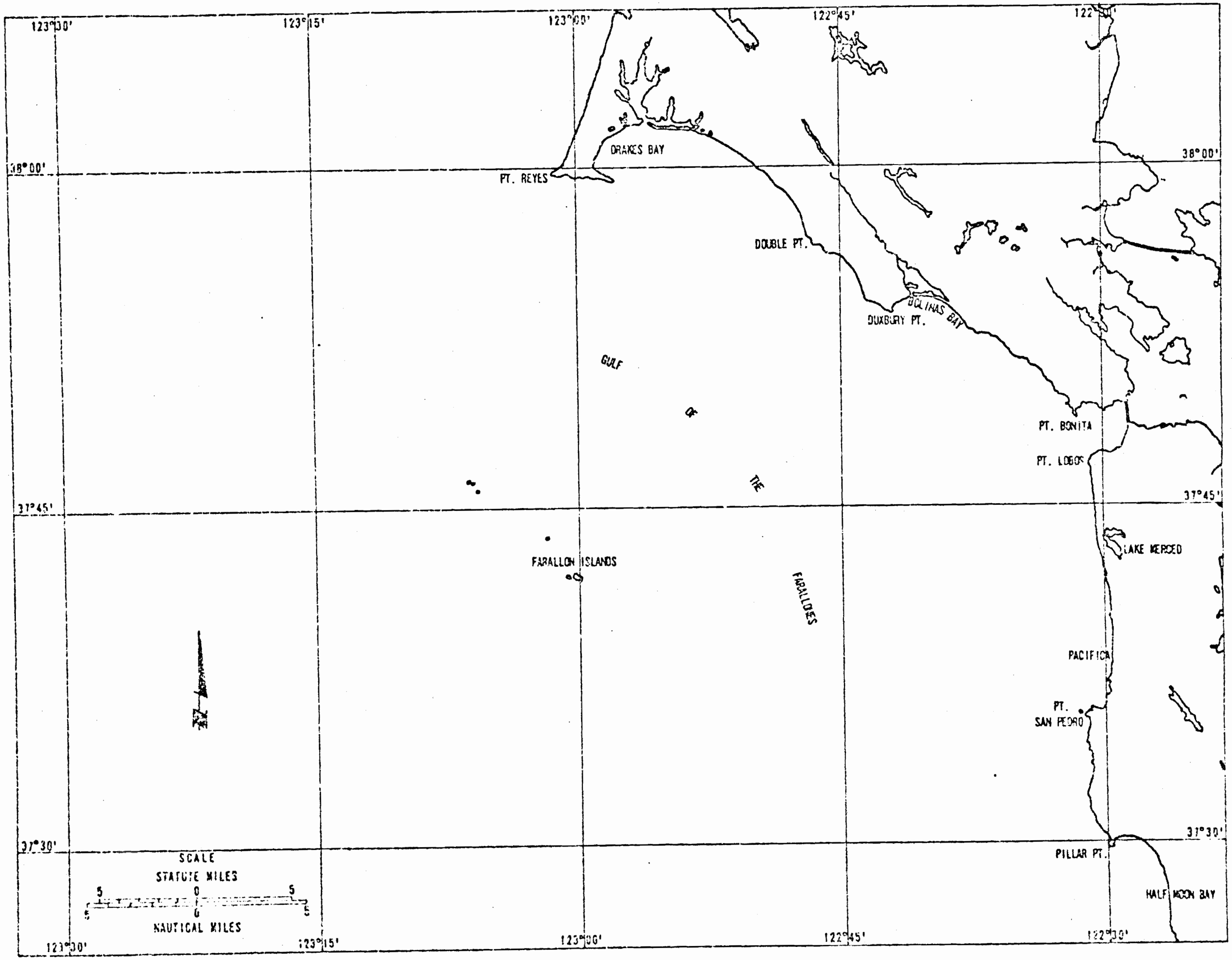

FIGURE 2. Ocean study area of Dungeness Research Program.

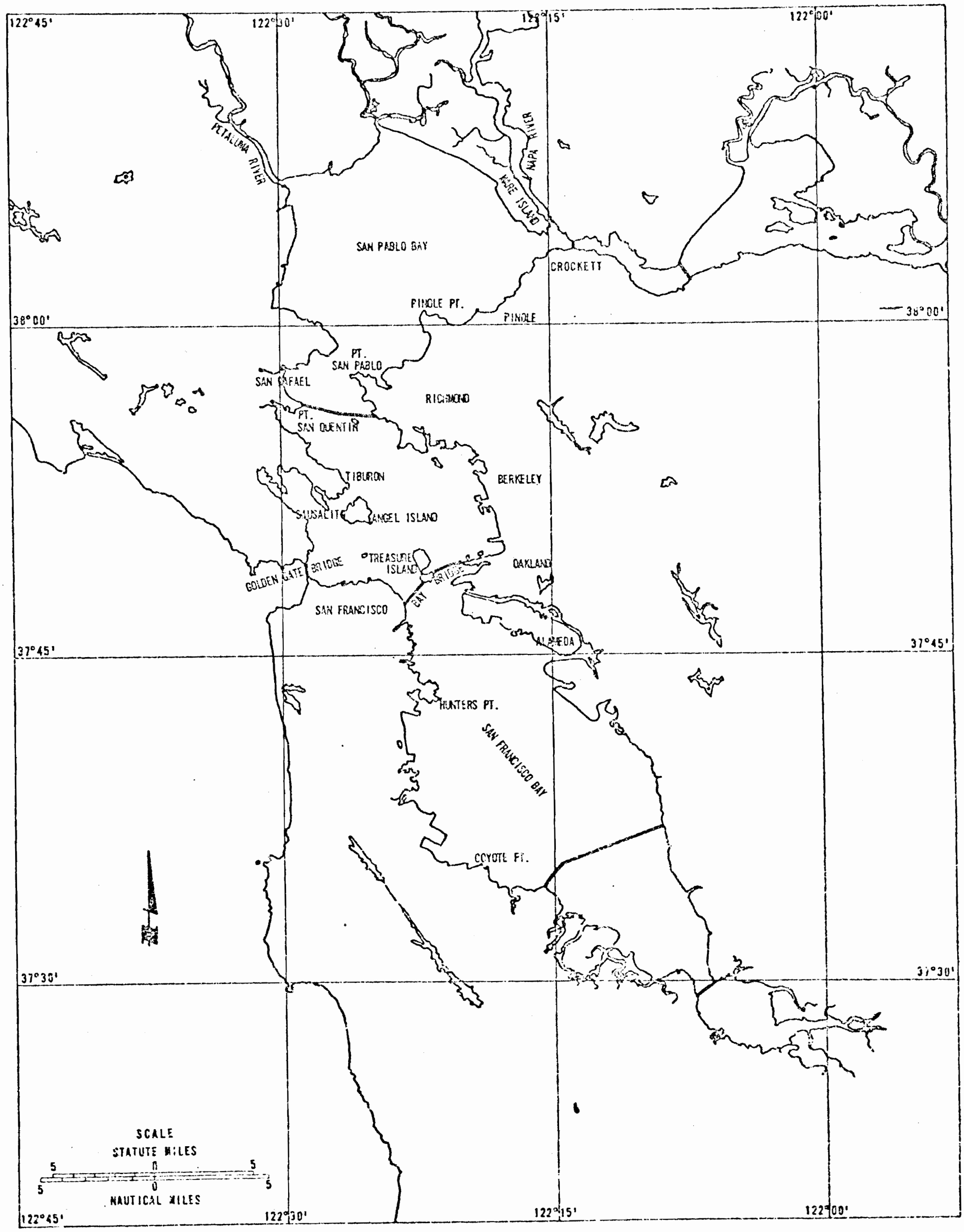

FIGURE 3. Bay study area of Dungeness Crab Research Program.

supplemented by several smaller cruises of 1 to 4 days duration. Nearly 400 plankton tows and over 200 trawl tows were made in 1977. In addition, 12 plankton tows were made in ocean waters near Eureka to obtain comparative data.

Plankton sampling began in January to coincide with the hatching of larval crabs. As the larvae developed toward the juvenile stages over the next 4 months, less emphasis was placed upon plankton towing and more upon bottom trawling.

Our first major cruise occurred January 27 to February 5, 1977, aboard the R/V *Alaska*. One hundred seventy-four plankton tows were made at 34 stations in the Gulf of the Farallones and four tows were made in central San Francisco Bay. We made seven tows at night in an initial attempt to determine any differences in availability caused by diurnal vertical migration of the larval stages. Generally, station occupation in the Gulf was identical to our plankton surveys in 1976 with surface, oblique, and three mid-column horizontal tows. However, we replaced our original 505-micron opening-closing net with a 12-inch (30-cm) Clarke-Bumpus sampler of similar mesh size and opening-closing capabilities for all discrete-depth tows below the surface. Salinity and temperature measurements were taken at all horizontal towing levels including the surface and bottom (when possible) on this and all successive cruises. Thirteen trawls were made to collect adult Dungeness crabs for reproductive studies being carried out at the Department's Marine Culture Laboratory.

In early February we made nine oblique plankton tows in San Pablo Bay from the *Striper II* using a 0.5-m (1.6-ft) diameter net with 1-mm mesh and adapted to a towing sled.

We collected six plankton samples each on February 15 and April 21 in the Eureka area from the P/V *Bluefin*. One tow was made at each of six stations spaced 5 nautical miles (8 km) apart along a transect perpendicular to the coastline from the entrance to Humboldt Bay and out to 30 miles (50 km).

Cruise 77-A-4 began on March 12 and was terminated abruptly on March 14 when the *Alaska* was recalled to southern California for an emergency anchovy survey. Nine plankton samples had been collected in the Gulf at three stations and four oblique tows had been made at four stations in the Bay complex. To compensate for the loss of ship time, we chartered the 65-ft *Little Bear* from the California Maritime Academy March 25-27. We made one oblique plankton tow at each of 11 stations in the central and northeast sections of the Gulf. The aborted cruise was rescheduled for April 6-11 (77-A-5). One hundred one plankton samples were collected in 6 days using two teams of two biologists each working 10-hr shifts. We collected 34 of these samples at night, dawn, or dusk, and of these, 24 were replicate tows at stations sampled during daylight hours. Each station consisted of an oblique and surface tow. Stomachs were removed from various demersal fishes and preserved in 10% formalin.

We initiated the first of a series of three *Kelp Bass* cruises in May. The first cruise ran from May 9-17 (77-KB-3). We continued to anticipate the presence of larval *C. magister* in the water column, particularly megalopae, but placed an equal effort on bottom trawling for the new post-larval instars. We occupied 21 stations in the Gulf of the Farallones and 29 (14 by skiff) in San Francisco and San Pablo Bays.

During the next cruise 77-KB-4 (June 13-26) we intended to sample only by trawling, assuming that all or most of the 1977 year class had metamorphosed to the early post-larval stages. However, we encountered vast sporadic assemblages of the coelenterate *Vellela vellela* and, upon dipnetting some of them out of the water, discovered attached *C. magister* megalopae. We then made one oblique tow at each of 11 stations to determine if megalopae also were present in the water column. We made bottom trawl tows at 21 stations in the Gulf and 29 stations (10 by skiff) in the Bay complex. Again, stomachs of various demersal fishes were collected and preserved.

On cruise 77-KB-9 (September 21-October 7), 18 stations were occupied in the Gulf of the Farallones and 20 stations in the San Francisco-San Pablo-Suisun Bay complex. Stations consisted of 5- or 15-min bottom trawl tows and a 45-min set with five baited ring nets. Sixty-eight stomachs of various demersal fishes were collected.

That portion of the 1976 year class that resides in the Bay complex was monitored in January and February by trawl and ring net from the *Striper II*. Crabs of the 1977 year class are being monitored in the Bay from the *Crago*. This vessel is much faster than the *Striper II* and allows us to occupy 15 stations from Suisun Bay south to the Dumbarton Bridge.

Sixteen shore-based ring netting stations were established in June from Port Chicago in Suisun Bay to Redwood City in south San Francisco Bay. Three 30-min sets with five baited ring nets are made monthly at each station. Salinity and temperature measurements also are taken.

Results and Discussion

Larvae. We are unable to compare statistically the catch-per-unit-of-effort of our Dungeness crab larval samples; yet the differences between the

1976 and 1977 year classes appear to be considerable but not consistent. Our plankton tows in January 1976 aboard the P/V *Tuna* yielded stage I zoeae in densities as high as 9000/1000 m^3; yet in 1977 the highest density we found was 140/1000 m^3. Conversely, densities of megalopae in 1976 never exceeded 40/1000 m^3; yet in 1977 densities were as high as 430/1000 m^3 for day tows and 330/1000 m^3 for night tows. The disparity in stage I zoeae densities most likely is a feature of the time of sampling. Our biweekly transects aboard the *Tuna* from December 1975 to February 1976 allowed us to infer the onset of the first major hatching period in 1976 as the first 2 weeks in January. The first 1976 stage I zoeae were collected January 14, 1976. The highest stage I densities occurred on January 30, at which time we collected the first stage II zoeae. The initial stage IV zoeae were collected February 11. Sampling in 1977 began January 27, at which time we collected one stage IV zoea along with low densities of stages I, II, and III. Therefore, it appears that our sampling effort missed the major 1977 hatching period by as much as 1 month and that the hatching period occurred several weeks earlier than in 1976.

The pattern of *C. magister* larval distribution, based on data from 1976 and 1977 appears to be as follows:

1. A major period of hatching occurs nearshore in late December or early January.
2. A small amount of hatching occurs intermittently throughout winter and into spring. Stage I zoeae were found in the Gulf of the Farallones as late as mid-May in 1977.

3. The larvae drift offshore throughout the winter. Stage I zoeae have been captured as close to shore as it is possible to sample. Stage III zoeae have been found no less than 13 miles (21 km) from shore. Stage IV zoeae, with the exception of one occurrence in the extreme northern section of the Gulf, have not been collected within 22 miles (35 km) of shore. We found no stage V zoeae either in 1976 or 1977. No *C. magister* zoeae were found in any of our 1977 Bay samples.
4. Megalopae appear, generally in higher densities than late stage zoeae, from late March to late June throughout the Gulf and occasionally in the Bay complex. In 1976, during the period in which megalopae were present in the Gulf, 138 plankton tows yielded only 14 megalopae. During a similar period in 1977, 158 plankton tows yielded 397 megalopae. The highest densities occurred in the north central section of the Gulf. Megalopae were collected at all Gulf stations except some in the southern part.

The aforementioned findings, when viewed in light of the upwelling pattern along the central California coast, suggest the possibility of recruitment of megalopae from northern California spawning stocks and the loss of local larval stocks due to a continual movement of offshore surface waters during the larval season. This must be studied more fully.

Recently analyzed plankton samples taken by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) in February and March 1950 support the contention that the larvae of *C. magister* drift offshore as they develop. Zoeal stages IV and V were found 67 miles (107 km) off San Francisco.

This documents the first occurrence of stage V in our records. Stage V zoeae also were found 111 miles (177 km) offshore during February and 150 miles (239 km) during March. Megalopae were found 154 miles (247 km) from shore during March. All these records occurred along CalCOFI transect line 60 which runs perpendicular to the coastline off San Francisco.

Over the next 2 years we plan to analyze nearly 400 CalCOFI plankton samples to supplement our own collection efforts. Arrangements have been made with the curator of plankton at Scripps Institution of Oceanography to borrow the samples collected from 1949 through 1973 along four transects (two each) off central and northern California.

The majority of 1977 year class megalopae was collected during 77-A-5 (April 6-11). A few were collected in May in an area north and northeast of Southeast Farallon Island. In June 1977, when most crabs of the year were in the early post-larval stages, we discovered megalopae attached to *Vellela vellela*. Although patches of *Vellela* were found throughout the Gulf, dipnetting yielded megalopae only on those *Vellela* collected north of Point Bonita (entrance to San Francisco Bay) and within 12 miles (19 km) of shore. No megalopae were caught in 11 oblique plankton tows from this area. Apparently *C. magister* does not make exclusive use of *Vellela*. The megalopae of *C. gracilis*, *C. oregonensis*, and a larval stage of the sand crab, *Emerita analoga*, also were found on these coelenterates.

The results of our day versus night sampling are not yet supported by statistics; however, it appears as though brachyuran densities, particularly zoeae, are greater at night on the surface at our offshore stations and that the abundance of *C. magister* megalopae is not related to time of sampling. The vertical migration of zooplankters, as well as more favorable wind conditions, make night sampling advantageous when cruise time is at a premium.

Results of the Eureka plankton sampling suggest that larval development of *C. magister* was proceeding at approximately the same time as the Gulf population. We found zoeal stages I through IV in the February sample and megalopae at four of the six stations sampled in April. Larval densities do not appear to be significantly greater near Eureka when compared to Gulf samples. The highest density we found for any single zoeal stage in Eureka was 105/1000 m^3 for stage III, and megalopal densities did not exceed 40/1000 m^3.

The Clarke-Bumpus plankton samplers did not prove to be satisfactory. The mouth diameter was only one-half the size of previously used opening-closing plankton nets, and the design of the device somehow impeded water flow at increased speeds. These two features make their use impractical at our offshore stations where brachyuran densities are generally very low. The samplers also are prone to numerous and varied mechanical difficulties, and because of their size and rigid construction, are hazardous to work with in heavy seas, or high winds, or both. The opening-closing mechanism malfunctioned frequently thus contaminating many of the discrete-depth samples. We will discontinue the use of the Clarke-Bumpus samplers and return to our standard 0.5-m opening-closing nets for the 1978 larval season.

<u>Intermolt staging study</u>. A research project was begun using a method of intermolt staging to determine age distribution of the megalopal stage of *C. magister* in the Gulf of the Farallones. The subjects of the study are megalopae netted during plankton sampling in April, May, and June of 1977. A continual or stepwise change in the intermolt stage along any axis may be evidence of directional movement.

Preliminary staging was carried out with laboratory-reared *C. gracilis* megalopae because they were immediately available in large numbers at our Marine Culture Laboratory. A series of stages was described from observations of setal development in the 2nd maxilliped and telson and from the apolysis and structural development of the new uropods. A continual series was obtained for the entire time (about 23 days) the crabs were in the megalopal stage with the exception of days two through eight; for these days, no discernible changes occurred. Further work with stains may make development during these days evident.

C. magister megalopae have been obtained recently from the Marine Culture Laboratory and U.C. Berkeley's Bodega Marine Laboratory. This reference series will allow us to begin work on the field samples. Since the 1977 series is somewhat incomplete, we will need to augment our collection with a new series next year.

Temperature influences. Unusually warm temperatures were detected in the Gulf of the Farallones during late January and early February of 1977 (77-A-2). Offshore water temperatures generally were greater than 12.5 C (55 F) between the surface and 25 m (83 ft). It appeared that a large intrusion of oceanic water had entered the Gulf. Warmer water might explain the occurrence of two previously unencountered and as yet unidentified species of *Cancer* larvae. Presently we are able to identify the larvae of the following species of *Cancer: magister, oregonensis, productus, gracilis, anthonyi,* and *antennarius*. At least one of the unidentified species appears to be associated with this warm water mass because larval densities increased with distance from shore in contrast to local populations of cancrid crabs. The usual pattern of upwelling appeared to be present in April (77-A-5) when surface temperatures in the Gulf ranged between 8.5 and 9.5 C (47 and 49 F).

Associated zooplankters. The specific hydrographic requirements of zooplankters in association with *Cancer magister* (e.g. chaetognaths) may help us understand the movements of local water masses and possibly the distribution of *C. magister* larvae. Species of the phylum Chaetognatha have been found to be convenient and accurate biological indicators. Species common to central California include *Sagitta euneritica, S. bierii, S. decipiens*, and *S. scrippsae*.

During April and May 1976, plankton sample analysis revealed a predominance of *S. decipiens*, an oceanic, mesopelagic species, in nearshore waters. The movement of cooler, deep upwelling waters toward the coastline would explain large numbers of this species in the upper water layers. The presence of *S. bierii* in the study area also indicates an upwelling regime as it is a deep-dwelling, offshore species commonly found in areas of mixing. The absence of the characteristically epineritic chaetognath *S. euneritica*, suggests that unusually strong upwelling occurred during these months. *S. euneritica* probably was transported offshore and was replaced by *S. bierii*.

Our plankton samples from late May and June 1976 suggest that upwelling was still occurring off the central California coast. The nearshore occurrence of *S. scrippsae* and *Eukrohnia hamata*, oceanic species rarely seen at the surface, supports this assertion.

Samples collected in January 1977 indicate a significant warm-water encroachment into our study area. Large numbers of two, oceanic, warm-water chaetognath species, *S. enflata* and *S. minima*, were found. *S. enflata* generally is distributed south of central California, and *S. minima* is an exclusively offshore form found primarily in the waters over the edge of the continental shelf. In addition, relatively small but significant numbers of *S. zetesios*, *S. hexaptera*, and *Krohnitta subtilis* were found. All three of these species are warm-water forms, particularly *K. subtilis*, which is primarily subtropical and rarely found in our sampling area.

The zooplankton assemblage during January 1977 proved to be very diverse. The appearance of the warm-water euphausid *Nyctiphanes simplex*, rarely seen north of Point Conception, indicated the degree of warm water encroachment. Densities in our waters measured as high as 2040 individuals per 1000 m^3.

Juveniles. Early-stage post-larval instar crabs of the 1977 year class were first found in stomachs of fish taken from the Gulf on April 11. On May 12 we collected crabs of similar size in the Bay in trawls. During cruise 77-KB-3 (May 5-22) we trawled for over 700 min and netted nearly 2000 crabs. Fifty-seven percent of our total effort was expended in the Bay and yielded 72% of the catch. Eighteen of 30 Bay stations yielded 1977 year class crabs yet only four of 21 Gulf stations did the same. One station alone, located in Drakes Bay, was responsible for over 80% of the Gulf collected crabs. The Bay crabs were distributed predominantly along the channel banks in north San Francisco and San Pablo Bay. This pattern is likely the result of prevailing bottom currents which would direct newly metamorphosed post-larval stages into the Bay complex from the Gulf.

Cruise 77-A-4 (June 13-22) was much like the previous one. Approximately 1600 crabs-of-the-year were collected in just over 500 min of trawling. Catch-per-unit-of-effort (CPUE) rose for Bay collected crabs from approximately three and one-half to five crabs per minute of trawling. Effort in the Bay was reduced to 40% of the total, but the catch only dropped to 63% of the total. Bay collected crabs appeared to be moving out of the channel areas onto the mudflats. Although 25 of 29 Bay stations yielded crabs, north San Francisco and San Pablo Bays continued to dominate the catch with San Pablo Bay becoming increasingly important. CPUE in the Gulf remained for the same at about two crabs per minute of trawling. Only four of 24 stations yielded crabs; as in May, over 80% of the total Gulf-collected crabs came from Drakes Bay.

From September 21 to October 3 (77-KB-9) we conducted a trawl CPUE survey to determine the percentage of crabs that entered the Bay complex to use it as a nursery ground. Reflecting natural mortality rates, the trawl CPUE in the Bay dropped from 5.0 to 2.6 crabs/min and in the Gulf from 2.0 to 0.5 crabs/min. These data suggest that approximately 80% of the 1977 year class resided in the Bay. This figure compares favorably to our survey estimate of 80% for the 1975 year class but contrasts dramatically to the estimate of 33% for the weak year class of 1976. Our 1976 annual report indicated that the percentage of 1976 year class crabs residing within the Bay was 51%; however, this figure has been adjusted because it included ring-net data which were found to be biased in favor of Bay stations. The three survey years now project figures generated by trawls only. The CPUE, lumping all possible trawl data together, from 1975, 1976, and 1977 is 1.2, 0.2, and 2.5 crabs/min, respectively. These are not statistically refined estimates and are difficult to compare because we used a mixture of trawling gear types throughout the years, but we do believe they approximate the relative abundance of these year classes within a few months after settling of the larvae.

Our shore sampling stations initiated in June 1977 were designed to monitor the entire Bay complex because the drought in northern California increased salinities in the estuary. We were not surprised to find that by August our two sampling stations east of the Carquinez Bridge in Suisun Bay (Port Chicago and Benicia) showed heavy concentrations of Dungeness crabs. By October the salinity at Port Chicago dropped to 12.5 ‰ and this drop was reflected in a reduction of the October and November catch. The catches of crabs at our south San Francisco Bay stations, always lower and more sporadic than the rest, became almost nonexistent in October and November. Concurrent with these reductions, the catches at our north San Francisco Bay and San Pablo Bay stations rose and reflected what appears to be a consolidation of crabs in that area.

In November we initiated a 4-month (November to February) trawl and ring-net survey from the 23-ft vessel *Crago* with stations that correspond to the shore-based ring netting stations. The data collected to date from the boat parallel those from the shore.

Predation

Four hundred seventy-six fish stomachs collected during our 1976 cruises were examined. We identified stomach content items to the lowest taxon possible. All *C. magister* juveniles found in stomachs were measured and sexed when possible. We feel that relative strengths of year classes are reflected by the frequency of occurrence of *C. magister* in fish stomachs. The total number of *C. magister* found in fish stomachs and the percentage of stomachs containing *C. magister* were much higher in 1977 than in the previous 2 years, particularly 1976 (Table 2); thus, 1977 appears to be the strongest of the year classes and 1976 the weakest.

TABLE 2. Occurrence of *C. magister* in Fish Stomachs, 1975-1977.

	Gulf of Farallones			Bay complex		
	1975	1976	1977	1975	1976	1977
No. stomachs examined	333	356	506	279	120	416
No. containing *C. magister*	8	4	71	27	5	76
% containing *C. magister*	2.4	1.1	14.0	9.7	4.2	18.3
No. megalopae in stomachs	17	6	75	3	1	0
No. juveniles in stomachs	8	1	1233	66	6	266

From cruise 77-A-5 (April 4-11) nine of 34 fish stomachs (26.5%) collected from two Gulf stations yielded 55 *C. magister* megalopae and six first stage post-larval instars. We found no *C. magister* in 104 stomachs taken from the Bay during the same week; however, we did collect 16 megalopae in two oblique plankton tows indicating that some young-of-the-year entered the Bay system but had not settled yet.

The results of 77-KB-3 (May 5-22) clearly indicated a stronger year class in 1977. Of 188 fish stomachs analyzed from Gulf stations, 27 (14.4% contained 15 megalopae, 1056 young-of-the-year, and one older *C. magister*. Of 209 Bay collected fish stomachs, 61 (29.2%) contained 214 young-of-the-year and two older *C. magister*. No other brachyuran occurred at such a high frequency and magnitude.

We examined 246 fish stomachs collected from Gulf stations during cruise 77-KB-4 (June 13-26). Twenty-six stomachs (10.6%) contained five megalopae and 158 young-of-the-year. Of 75 fish stomachs from Bay stations, 12 (16.0%) contained 49 young-of-the-year *C. magister*.

We collected 68 fish stomachs (38 Gulf, 30 Bay) during 77-KB-9 (September 22-October 7) to determine if predation continued into the fall. Nine stomachs (23.7%) from the Gulf yielded 13 young-of-the-year and one older crab. Only three stomachs (10.0%) from the Bay contained crabs. The steady decline in frequency of occurrence of *C. magister* in fish stomachs from the Bay is not caused necessarily by mortality alone. The relatively faster growth rate for Dungeness crabs in the Bay allows them to reach a size less vulnerable to predation by September. Most of the crabs collected in the Bay were greater than 40 mm (1.6 inches) carapace width (CW) and only three crabs (two of them greater than 40 mm CW) were found in fish stomach samples. In the Gulf the majority of the young-of-the-year crabs collected by trawl were in the 15- to 40-mm (0.6- to 1.6-inch) CW size range, and, concurrently, predation occurred more frequently.

The size frequencies of young-of-the-year crabs collected in fish stomachs agree well with those collected by trawl. In the Gulf in early April, most of the crabs found in fish stomachs were in the megalopal stage and no young-of-the-year were caught in trawls. By June we found that most of the crabs were young-of-the-year 6 to 21 mm (0.2 to 0.9 inches) CW; only a few were still megalopae. In September the few crabs collected in fish stomachs measured between 14 and 33 mm (0.6 and 1.3 inches) CW.

In the Bay most crabs from fish stomachs collected in June measured 14 to 33 mm CW with a few between 40 and 44 mm (1.7 inches) CW. The three crabs collected from fish stomachs in September measured 29, 48, and 60 mm (1.1, 1.9, and 2.4 inches) CW.

Further evidence that predatory fish can reflect the relative abundance of young-of-the-year crabs comes from a comparison of trawl CPUE (crabs per minute of trawling) to predation magnitude (crabs-per-fish-stomach for all fish collected at a given station). Of 29 Bay stations sampled, the 10 trawl catches with the highest CPUE occurred at stations in the main ship channel in north San Francisco and San Pablo Bays. These same stations accounted for 10 of 11 of the best yields of crabs from fish stomach analyses.

A similar situation occurred in the Gulf stations. Four of 21 Gulf trawl stations yielded young-of-the-year crabs. Crabs were found in fish stomachs from eight stations, including the aforementioned four trawl stations.

Not only do demersal fish stomach contents appear to reflect crab year class strength, but the fish seem to be more efficient in sampling the new crab year class than our traditional methods.

Twelve stomachs from commercially caught silver salmon, *Oncorhynchus kisutch*, were collected by non-project personnel in early May 1977 from various sections of the Gulf of the Farallones. We previously have not examined stomachs from *O. kisutch*, but it appears that this predator has the potential to cause significant mortality during the Dungeness crab's megalopal stage. Eight of the stomachs examined contained 1061 megalopae.

We compiled a list (Table 3) of all fish species in which we have found *C. magister* from 1975 to the present in order of decreasing impact on the crab population. The relative strength of the 1977 year class is again evident from the total number of fish species found to have eaten crab larvae in 1977 and from the average number of crabs per stomach. We have examined stomachs from 60 species of fish and 25 have fed on *C. magister*.

TABLE 3. Predators of *Cancer magister*, 1975-1977

Gulf of the Farallones				San Francisco-San Pablo-Suisun Bay Complex			
Scientific name	Common name	No. stomachs examined	Mean no. crabs/ stomach	Scientific name	Common name	No. stomachs examined	Mean no. crabs/ stomach
1975				1975			
Scorpaenichthys marmoratus	cabezon	1	1.0	*Acipenser medirostris*	green sturgeon	1	6.0
Platichthys stellatus	starry flounder	23	0.9	*Mustelus henlei*	brown smoothhound	11	1.4
Rhacochilus toxotes	rubberlip surfperch	3	0.7	*Raja binoculata*	big skate	3	1.3
Leptocottus armatus	staghorn sculpin	8	0.2	*Leptocottus armatus*	staghorn sculpin	98	0.3
Raja binoculata	big skate	10	0.1	*Platichthys stellatus*	starry flounder	72	0.2
Glyptocephalus zachirus	rex sole	41	0.1	*Genyonemus lineatus*	white croaker	40	0.1
1976				1976			
Platichthys stellatus	starry flounder	23	0.1	*Triakis semifasciata*	leopard shark	2	0.5
Genyonemus lineatus	white croaker	18	0.1	*Mustelus henlei*	brown smoothhound	15	0.1
Sebastes caurinus	copper rockfish	2	0.1	*Leptocottus armatus*	staghorn sculpin	32	0.1
Citharichthys sordidus	Pacific sanddab	22	0.1	*Genyonemus lineatus*	white croaker	30	0.1
1977				1977			
Oncorhynchus kisutch	silver salmon	12	88.4	*Acipenser medirostris*	green sturgeon	4	10.0
Acipenser medirostris	green sturgeon	1	53.0	*Raja binoculata*	big skate	18	1.9
Acipenser transmontanus	white sturgeon	1	36.0	*Mustelus henlei*	brown smoothhound	57	1.7
Platichthys stellatus	starry flounder	44	20.4	*Damalichthys vacca*	pile surfperch	22	1.6
Hexagrammos decagrammus	kelp greenling	4	8.7	*Platichthys stellatus*	starry flounder	46	0.5
Lepidopsetta bilineata	rock sole	7	8.6	*Myliobatis californica*	bat ray	2	0.5
Raja binoculata	big skate	23	4.0	*Leptocottus armatus*	staghorn sculpin	49	0.4
Parophrys vetulus	English sole	50	1.5	*Parophrys vetulus*	English sole	3	0.3
Mustelus henlei	brown smoothhound	6	1.2	*Genyonemus lineatus*	white croaker	50	0.3
Amphistichus rhodoterus	redtail surfperch	1	1.0	*Phanerodon furcatus*	white surfperch	4	0.2
Hyperprosopon anale	spotfin surfperch	3	0.6				
Genyonemus lineatus	white croaker	34	0.6				
Microgadus proximus	Pacific tomcod	24	0.5				
Sebastes pinniger	canary rockfish	2	0.5				
Leptocottus armatus	staghorn sculpin	25	0.5				
Damalichthys vacca	pile surfperch	5	0.2				
Merluccius productus	Pacific hake	24	0.1				
Citharichthys sordidus	Pacific sanddab	52	0.1				

CRAB ENVIRONMENT PROJECT STUDIES

by

Paul W. Wild and Charles W. Haugen[5/]

During 1977 the Dungeness Crab Environment Project continued investigations of natural and man-caused changes in the environment which could be related to the long-term decline in the San Francisco area crab population and low commercial fishery landings. Work continued on two major sub-units: natural environmental factors and environmental toxicants.

Natural Environmental Factors

Work was directed toward statistical analyses of historical oceanography versus crab landings, laboratory experiments on the relationship between crab spawning and seawater temperatures, and studies of reproductive development and mating success in female crabs.

Oceanography Versus Crab Landings and Life History

Work continued during 1977 on correlating oceanographic parameters with crab landings data. We concentrated on the San Francisco area this year.

Environmental factors may affect, favorably or unfavorably, crab abundance at any stage in the life history. Any significant fluctuations in crab abundance should be reflected in commercial crab landings.

In central California a majority of crabs enter the commercial fishery (males only may be taken legally) at about 3 years of age while some are taken as early as 2 or as late as 4 years of age or older. Commercial fishery landings are thought to be representative of the size of the population and a rough index of year-class strength of 3 year old crabs. By allowing

5/ Operations Research Branch, 2201 Garden Rd., Monterey, CA. 93940 appropriate lag times, regressions can be used to test for effects of environmental conditions on crab abundance.

Methods and Materials. Two types of regression analyses were run: (1) simple regressions comparing crab landings to individual oceanographic parameters including the periods from 1948-1961 (pre-decline years), 1962-1975 (years during the decline), and the entire period from 1948-1975; and (2) stepwise, backward, multiple regressions for the period from 1948-1974.

In both sets of regression analyses oceanographic data were grouped into quarters which coincide with specific life history phenomena and approximate oceanographic periods (Table 4).

TABLE 4. Corresponding Quarters, Dungeness Crab Life History Stages, and Oceanographic Periods.

Quarter	Dungeness crab life history stage	Oceanographic period
Dec - Feb	Eggs hatch. Early larval stages present in plankton.	Davidson Current period.
Mar - May	Larval development and metamorphosis to early crab instars. Adult females molt and mating occurs. Large juveniles begin leaving San Francisco Bay.	Early upwelling period.
Jun - Aug	Adult males molt. Large numbers of small juveniles have migrated into San Francisco and San Pablo Bays.	Peak upwelling period to onset of oceanic period.
Sep - Nov	Females spawn, brood eggs.	Oceanic period to onset of Davidson Current period.

Lag times of 0 to 4 years between oceanographic parameters and landings data were used in the regression analyses. Oceanographic parameters included sea surface temperatures and densities, Monterey Bay temperatures at 30-m depth, upwelling at Point Arena and Point St. George, wind stress curl, sea level corrected for atmospheric pressure, uncorrected sea level, atmospheric pressure and river flow rates (estimated flow through the Delta into San Pablo Bay).

Results. In organizing data from the simple regressions for the periods 1948-1961 and 1962-1975 we selected correlation coefficients (r) of ± 0.60 or greater (99% level of significance, r = 0.641), and for 1948-1975 we selected r values of ± 0.50 or greater (99% level of significance, r = 0.470). In direct cause and effect relationships the square of the correlation coefficient (r^2) represents the percentage of the variation which is explained by the correlation. Even if a direct relationship exists, but the correlation is obscured by poor data, it would be difficult to discern the relationship from the resulting low r^2 values.

If a single environmental factor or a set of factors caused the drastic long-term crab decline, fairly high r values should be obtained assuming the data bases are reasonably accurate, precise, and complete. Commercial crab landings are not a very precise index of year-class strengths. Also, some of the oceanographic data series have occasional gaps, and the data points we used are monthly means which could obscure extremes which may be more important than means. Furthermore, for credibility as well as laboratory and field testing, any significant correlations must be explainable in terms of crab biology and oceanography.

Several of the r values from the simple regressions were greater than ± 0.60 for pre-decline and decline years and greater than ± 0.50 for the entire period (Table 5).

TABLE 5. Selected Correlation Coefficients from Simple Regressions of Crab Landings and Oceanographic Parameters* by Lag Time and Quarter.

Period	1948-1961				
Lag time (years)	0	1	2	3	4
Quarter					
Dec - Feb		(MBT) -0.66			(MBT) -0.62
Mar - May					(SST) -0.68
Jun - Aug	(WSC) -0.61 (MBT) 0.69	(WSC) -0.80		(MBT) -0.60	(USL) -0.69 (AP) 0.66
Sep - Nov	(MBT) 0.74	(AP) 0.62		(MBT) -0.79	(MBT) -0.83

Period	1962-1975				
Lag time (years)	0	1	2	3	4
Quarter					
Dec - Feb	(UPS) -0.70				
Mar - May		(UPA) -0.60			(AP) -0.66
Jun - Aug		(WSC) -0.71		(SST) -0.61 (CSL) 0.60	
Sep - Nov		(SSD) -0.64	(RF) -0.61		

Period	1948-1975				
Lag time (years)	0	1	2	3	4
Quarter					
Dec - Feb				(CSL) -0.50	
Mar - May				(WSC) 0.54	(WSC) 0.63
Jun - Aug				(CSL) -0.52	(USL) -0.63 (CSL) -0.62
Sep - Nov			(USL) -0.60 (CSL) -0.61	(WSL) -0.63 (CSL) -0.66	(UPS) -0.58 (USL) -0.60 (CSL) -0.61

* Oceanographic parameters

SST - Sea Surface Temperature
SSD - Sea Surface Density
UPS - Upwelling Pt. St. George
UPA - Upwelling Pt. Arena
WSC - Wind Stress Curl
USL - Uncorrected Sea Level
CSL - Corrected Sea Level
AP - Atmospheric Pressure
MBT - 30 m Monterey Bay Temperatures
RF - River Flow

Using the same quarters and oceanographic parameters as in the simple regressions (Table 4), multiple regressions were run with both landings and log values of the landings. The r values from multiple regressions cannot be expressed as simple positive or negative values so coefficient of determination (r^2) values are used.

The highest r^2 value (0.82) was obtained for the March-May period with a zero year lag between landings (log values) and seven oceanographic factors. This time quarter and its associated oceanography with a zero year lag occur after the major portion of the landings are taken each year. It is therefore extremely unlikely that any relationship exists, and we consider this correlation coincidental.

The coefficient of determination provides a measure of the proportion of the variation in landings explained by a regression analysis. Several r^2 values ranging from 0.61 to 0.73 were obtained with 2-, 3- and 4-year lags during December-February and September-November quarters. At least five or six oceanographic parameters remained in the regression in each of these. By referring to the simple regressions, the high r^2 values appeared to be bolstered largely by sea level values which are highly correlated to landings.

Discussion. Considering the limitations in using crab landings as an index of year-class strength and abundance of crabs, some rather strong correlations were obtained. However, the correlations must be explained in terms of crab biology and oceanography in order to support reasonable hypotheses relating to the crab decline. Some of the correlations can be rejected on this basis. For example, factors with 0- or 1-year lags would have to affect adult male crabs of legal and/or sub-legal sizes in order to affect crab landings. Possible causes of effects on landings could be large die-offs of adult crabs or large numbers of crabs not molting and reaching legal size before or during the commercial season. Evidence that these situations have not occurred is available from pre-season cruises from which the coming year's seasonal landings have been predicted with some success for quite a few years. Crab intermolt condition as determined on these cruises would have indicated if large numbers of crabs were delaying molting.

The correlations which appear to fit a reasonable hypothesis best are expressed in the r values for sea level data, both corrected and uncorrected, in the simple regressions for the period 1948-1975 (Table 5). Of these, corrected sea levels (atmospheric pressure removed) produced the highest correlation values.

Sea level data are considered good indicators of ocean currents which during the late fall and winter are represented locally by the Davidson Current, a south to north current along the California coast. Strong currents of this type at the time of hatching could carry larvae north out of the Gulf of the Farallones to areas where strong upwelling could sweep them out to sea. However, analysis of these data is being approached cautiously. Sea levels in the San Francisco area have been showing a gradual rise for many years. This is due possibly to land subsidence which lowers the reference point relative to the sea. However, if this rise were the cause of the correlation with crab landings, significant correlations might be expected to show up in all quarters with all lag times.

The sea level values also appear to be partly responsible for the high r^2 values in the multiple regressions. Analysis of all of the correlations is continuing, and combinations of data from different quarters are being considered for regression.

In addition, pre-season cruise data are being analyzed in an attempt to develop a better index of year class strengths for use in the regression analyses. Preliminary analysis indicates that these data may have some value for this purpose.

Crab Spawning and Water Temperature Relationships

Experimental work on the relationship between female Dungeness crab spawning and seawater temperature was continued at the Marine Culture Laboratory (MCL) during 1977. Continuing objectives are (1) to investigate relationships between ocean temperature and female crab spawning time and behavior, and (2) to investigate effects of ocean temperature and spawning on feeding rates in female crabs.

A preliminary, small-scale experiment begun in mid-1976 was completed in early 1977, and a more intensive experiment was begun in June 1977.

In the preliminary experiment a female crab held in seawater that was gradually raised to about 17 C during July and August, spawned on September 9, 1976. Another crab held in seawater at about 10 C had not spawned by late January 1977. The temperature was gradually raised to about 18 C during February and early March and this crab spawned on March 7, 1977. Two additional crabs died during the experiment without spawning.

The limited results of this preliminary work suggest that female crab spawning is related to a rise in water temperature. Whether the temperature rise induces spawning or hastens conditioning necessary for spawning was not determined. However, this preliminary work provided the basis for a more intensive experiment.

Methods and Materials. During June 1977, five aquaria with sand beds and aerated, sub-sand filters were set up at MCL. Each aquarium was divided into four compartments with dividers which allowed free water flow between compartments. The aquaria were supplied with filtered, ultraviolet-treated seawater. Four, recently molted, adult female crabs (two each from San Francisco and Eureka areas) were placed in each aquarium. The crabs ranged in size from 132 to 151 mm (5.2 to 6.0 inches).

The crabs were acclimated at ambient seawater temperatures for a few days before temperature control was begun. Two aquaria were supplied from a seawater reservoir with a refrigeration unit set to maintain the water at about 10 C. Two aquaria received seawater gradually raised to and held at about 17 C by mixing ambient and heated seawater. The fifth aquarium, which served as a control, continued to receive ambient laboratory seawater. Ambient temperatures fluctuated within limits between warm and cold controlled temperatures.

The crabs were fed pieces of squid, *Loligo opalescens*, to excess three times per week. This diet was supplemented with Pacific Ocean shrimp, *Pandalus jordani*, beginning with one per feeding on July 15 and increasing to two per feeding on August 1.

Observations of behavior, seawater temperatures, and amounts of food eaten were recorded three times per week.

Results. Temperature control was less precise than planned, particularly in the cold seawater (Figure 4). This was due to supplying water to two aquaria instead of one (as in the preliminary experiment), which required a higher water flow through the chilled seawater reservoir, and higher than usual air and ocean temperatures. These factors placed a heavy load on the

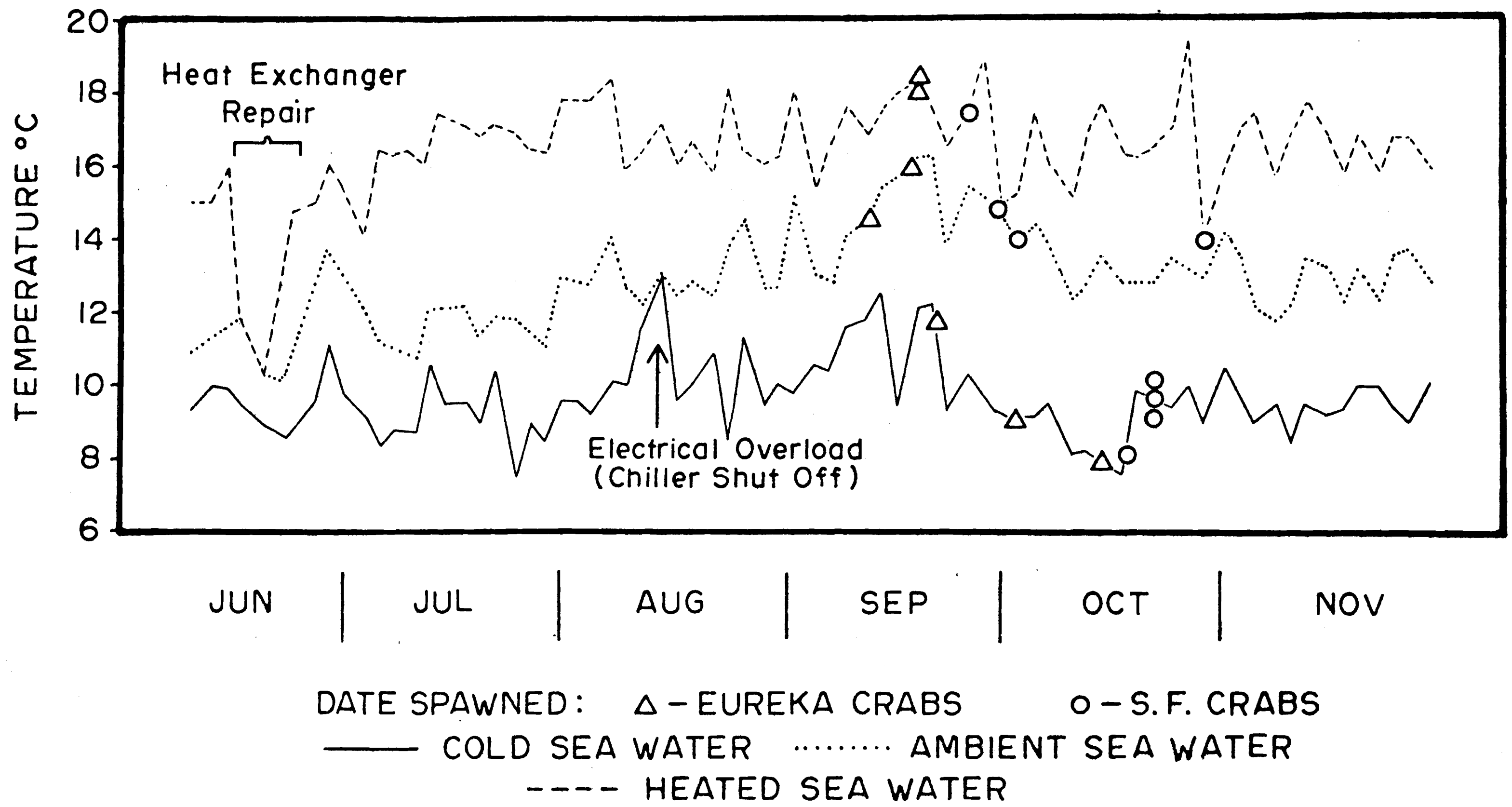

FIGURE 4. Date of spawning by female Dungeness crabs in three different laboratory seawater temperatures.

seawater chiller. Some temporary fluctuations in both warm and cold controlled temperatures were due to heat exchanger malfunction, electrical overload, and ocean intake-pump problems.

Crab survival generally was very good. One crab in cold water died a few days after we began the experiment and was replaced. Another crab in cold water died on June 22 and was not replaced. However, in mid-August, ocean intake-pump problems resulted in a severely reduced flow to one of the warm water aquaria. At the same time one of the aerators became plugged. By the time these conditions were noted, the four crabs in the aquarium were dead. All 15 remaining crabs appeared healthy and eventually spawned.

The first spawning occurred on September 12 by a Eureka area crab in ambient seawater. By October 28, all crabs in all three temperatures had spawned. Although this was unexpected in the cold seawater, some definite trends were evident in the time and order of spawning.

Spawning in each temperature regime appeared to coincide with or follow a gradual rise in seawater temperature (Figure 4). The gradual rise is more apparent in ambient and cold temperature profiles.

Overall, there was a tendency for crabs in ambient and warm seawater aquaria to spawn before crabs in cold seawater aquaria, especially when considered by area of origin. All Eureka area crabs in ambient and warm seawater spawned before Eureka area crabs in cold seawater; all but one San Francisco area crab in ambient and warm seawater spawned before San Francisco area crabs in cold seawater.

In each aquarium, in all temperature regimes, Eureka area crabs spawned before San Francisco area crabs.

Average feeding rates were initially higher during June and July for crabs in ambient and cold seawater. However, in August, feeding rates in ambient and cold seawater dropped somewhat while the rate for crabs in warm water continued to climb. These changes in feeding rates coincided with the increase of shrimp in the diet (Figure 5).

At about the time of spawning, feeding rates dropped drastically in all temperature regimes and remained low during the egg-brooding period. Crabs in warm water continued to eat the most food during this period.

Egg development proceeded faster in warm and ambient seawater than in cold. A crab in warm water which spawned on September 19 hatched larvae on November 22. Egg masses on the other early spawners in warm and ambient seawater appeared close to hatching by the end of November.

Discussion. The first ovigerous Dungeness crab in the wild was observed this year in the Gulf of the Farallones on September 28 during the September crab research cruise. By this time, six of the laboratory crabs (all but one from Eureka) had spawned. The first spawning of a laboratory crab from the San Francisco area was observed on September 21, which is very close to the onset of spawning this year in the wild. In 1976, crab spawning began in the Gulf of the Farallones in the first week in October. Although historical records of the onset of spawning are few, there is some evidence that the onset of spawning in 1976 and 1977 may be earlier than usual.

Difficulties in maintaining controlled temperatures as closely as planned precluded determination of whether a constant cold temperature would prevent spawning. Therefore, interpretation of the results must be

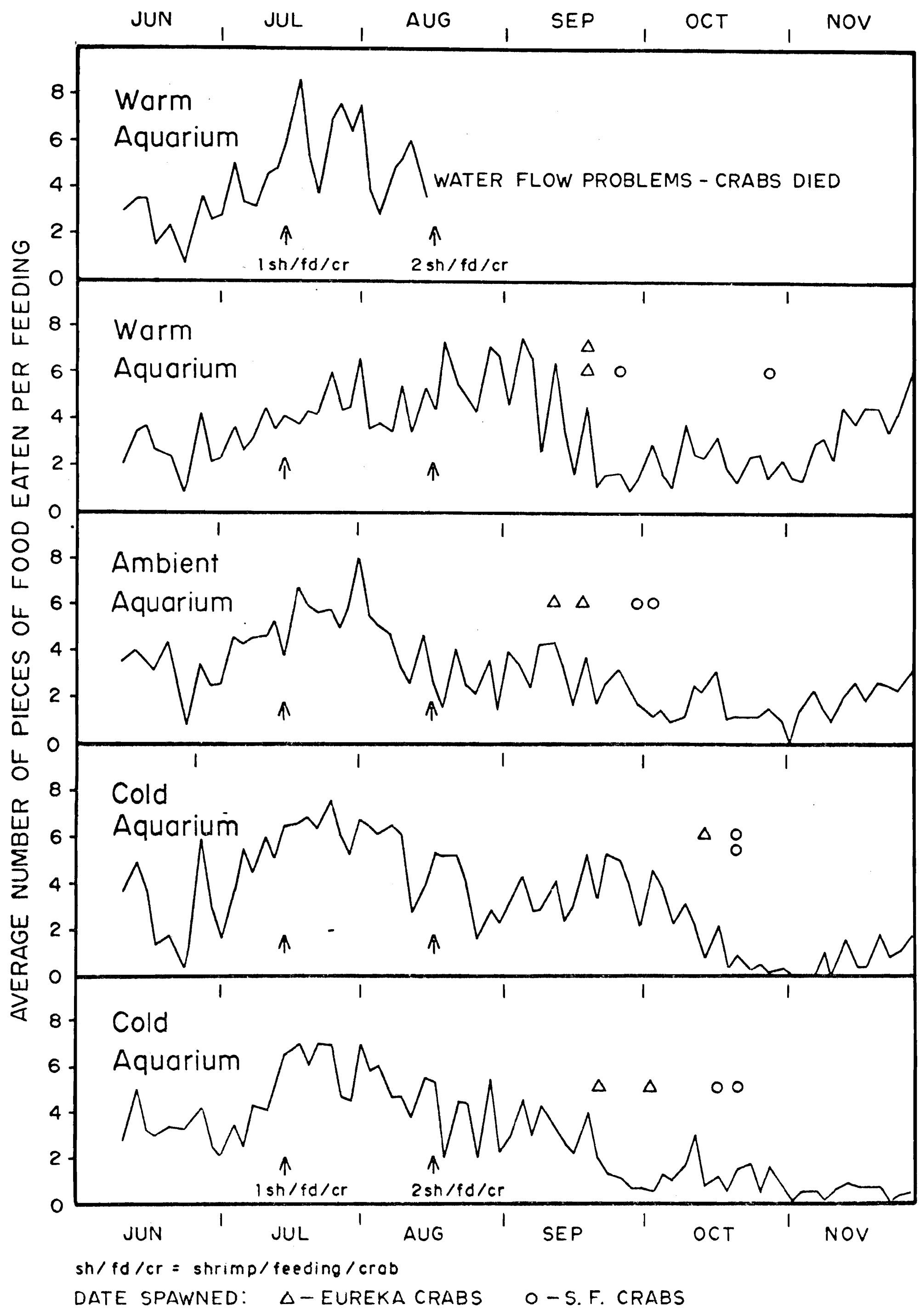

FIGURE 5. Average feeding rates and date of spawning by female Dungeness crabs in three different laboratory seawater temperature regimes. The crabs were fed pieces of squid to excess and shrimp as indicated three times per week.

approached cautiously. Nevertheless, nearly concurrent spawning following coincidental gradual temperature rises in all three laboratory temperature regimes appears to support a hypothesis that spawning is related to, and may be induced by, a temperature rise. However, the fact that crabs in warm water did not spawn soon after an initial temperature rise in late June (Figure 4) suggests that the ovaries were not mature enough for temperatures to affect spawning.

The earlier spawning by Eureka crabs in the laboratory is of interest because female crabs in northern California usually spawn and hatch larvae later than in central California. It may be that laboratory crabs from the Eureka area, being adapted to colder temperatures in the wild, responded faster to warmer experimental temperatures than San Francisco crabs which are adapted to temperatures closer to those in the experiment.

The effect of water temperature on feeding rates was more noticeable in warm water. A lower initial feeding rate in warm water may be an indication of greater stress during this period. However, as the crabs apparently adapted to the warm water, feeding rates rose as expected. The quick demise of the crabs in a warm water aquarium after water and air flows malfunctioned also suggests a lower tolerance to changes in the environment at these temperatures.

A drop in feeding rates in cold and ambient seawater after an increase of shrimp in the diet may be due to nutritional factors. Laboratory studies of juvenile crabs show a higher conversion ratio for brine shrimp than for squid. If this is also true for other crustacean food items such as Pacific Ocean shrimp, it could explain this drop.

Results of this experiment have important implications for understanding and observing effects of oceanography on the time of spawning and hatching and on distribution, abundance, and survival of crab larvae. Larvae hatched during the Davidson period could be swept north from the Gulf of the Farallones. The Point Arena area, about 160 km (100 miles) north of San Francisco, is noted for its strong upwelling usually beginning in the early spring. Larvae carried into this area could be swept far offshore before metamorphosis to the crab stage would occur.

We plan to continue the present laboratory experiment until all of the larvae hatch to obtain information on effects of water temperature on the time from spawning to hatching. We also plan to repeat the experiment in 1978 with more precise temperature controls.

Development of Ovaries and Mating Success

We continued to sample female crabs from the San Francisco and Eureka areas for comparative studies of ovarian development and mating success.

Methods and Materials. Female crabs were collected intermittently on research cruises, from Departmental patrol vessels, and from commercial fishermen. The crabs were frozen for later examination in the laboratory. We continued to determine ovarian development by weight and color as described in the 1976 program report. Mating success was determined by examination of dissected female reproductive tracts for presence of sperm in the spermathecae. Dissection techniques were modified this year to improve reproductive tract preparations for observation of mating success. Samples of reproductive tracts were preserved for microscopic examination of ova and sperm.

Results. From mid-1976 through November 1977, 103 crabs from the Eureka area and 272 from the San Francisco area were examined. Samples now have been examined for over one annual cycle for the San Francisco area and for most of an annual cycle for the Eureka area. Patterns in ovarian development and mating time and success are becoming evident.

In both areas development of ova begins soon after the crabs spawn and are still brooding eggs. However, the two populations soon begin to show different patterns of development. Average weights of the ovaries in crabs from the Eureka area are greater than in crabs of comparable sizes from the San Francisco area. This pattern becomes evident by April or May and appears to continue into the spawning season.

Whether the smaller ovaries in some San Francisco crabs are due to slower development of ova or fewer ova being produced than in Eureka area crabs is not clear yet. Development in these ovaries, as indicated by their color, in most cases appears to be progressing well by July or August. Completion of microscopic examination of ova may clarify this.

Improved dissection techniques have made us aware that determinations of mating success in 1976 were in error. Samples this year from both Eureka and San Francisco areas indicate a high level of mating success. In the June sample nearly 90% of the adult female crabs from the San Francisco area had molted and mated recently. A small sample from the Eureka area exhibited a similar trend. Preliminary results indicate that most of the mating occurs earlier in the San Francisco area than in the Eureka area.

Discussion. The relatively smaller ovaries in crabs taken off San Francisco could be due to the fact that crabs grow faster in this area, and more energy may be used for growth and sustaining a higher metabolism in the warmer water. Whatever the reason, there are implications for effects on crab productivity in the San Francisco area. Smaller ovaries would be expected to produce smaller egg masses and thus, fewer larvae. Such a lowered reproductive potential would make the crab population more susceptible to changes in oceanography and pollution. This aspect of reproductive potential needs to be explored further. We plan to continue with this work through 1978.

Environmental Toxicants

Work was directed toward (1) laboratory bioassays of toxic trace elements in juvenile Dungeness crabs, (2) completion of preliminary work on petroleum hydrocarbons in Dungeness crabs, and (3) preparation of proposals for augmentation, research on toxic trace elements, petroleum hydrocarbons, and effects of chlorine-treated wastes.

Toxic Trace Elements

Background. Earlier work has shown that crabs from the San Francisco area had much higher tissue levels of cadmium, silver, and selenium than those from the Eureka area (Orcutt et al. 1976). Work was begun to determine the significance of these higher levels by means of bioassays conducted at the Department's Marine Bioassay Laboratory (MBL) at Granite Canyon.

We believe that the greater part of these tissue burdens of toxic elements are acquired by the crabs as juveniles while residing in the San Francisco-San Pablo Bay complex. Therefore, juvenile crabs are used in the bioassays.

Before bioassays were begun, a study was undertaken to determine background levels of these three toxic elements in laboratory seawater at MBL and also in the tissues of juvenile crabs raised at the Marine Culture Laboratory (MCL). This study was supported by funding from the State Water Resources Control Board. Levels of cadmium in laboratory seawater and cadmium and silver in crab tissues were determined by atomic absorption spectrophotometry at Moss Landing Marine Laboratories. Seawater at MBL was found to contain 47 ± 1.15 parts per trillion of cadmium. A range of 10 to 150 parts per trillion is considered representative of clean to contaminated seawater, respectively. Tissue concentrations of cadmium averaged 0.50 ± 0.14 parts per million for instar II juveniles and 2.25 ± 1.13 ppm for older juveniles. Corresponding tissue levels of silver were 0.122 ± 0.03 ppm and 0.38 ± 0.05 ppm. Some techniques for determining silver and selenium levels in seawater and selenium in tissues were investigated and judged not feasible in the time allotted for this study.

Test Animals. During our June cruise (77-KB-4) large numbers of early-instar juvenile crabs were located in Drakes Bay. Approximately 2,000 of these were collected and transported to MCL to provide a supply of test animals for our bioassays.

Communal cultures of crabs experience high mortality rates primarily due to cannibalism. Therefore, we designed and built a system to hold over 1,000 juvenile crabs in individual cells. The others were placed in communal cultures for a reserve supply.

During the first 2 months the mortality rate was about 6% in the individual cells; most of the crabs had molted twice and mortality continued to be relatively low. By comparison, in a small communal culture being monitored for crab survival, 47% mortality occurred through the first molt, most of which was due to cannibalism.

Records are kept on time of molting in the individual cells for indication of intermolt stage when selecting crabs for bioassays.

Bioassays. Cadmium was chosen as the first trace element to be tested. A small-scale, range-finding, static bioassay was conducted preliminary to a full-scale, flow-through, acute bioassay. Four crabs were exposed to each of four concentrations of cadmium in seawater covering a thousand-fold range (0.1 to 100 mg/l). A control group of four crabs was maintained in laboratory seawater. Solutions were replaced every 24 hr. Crabs surviving 96 hr in test concentrations were maintained an additional 72 hr in laboratory seawater to detect any delayed mortality.

All crabs exposed to the highest concentration of cadmium (100 mg/l) were dead at the end of 24 hr. Half of the crabs in the 10 mg/l solution survived 96 hr. All of the crabs exposed to lower concentrations survived 96 hr in the cadmium solutions and an additional 72-hr period in seawater. There was no mortality among the control crabs. All crabs used in the test have been frozen and tissue levels of cadmium will be determined.

From the range-finding bioassay it appears the 96-hr LC_{50} for juvenile Dungeness crabs is in the neighborhood of 10 mg/l of cadmium in seawater. Full-scale, flow-through bioassays are in preparation which will use this value as a mid-point. Toward this end, a proportional diluter has been installed at MBL with which we will be able to hold 20 crabs in each of five concentrations of toxicants plus a seawater control.

Appropriate methods to determine levels of silver and selenium in seawater and selenium in crab tissues are under investigation. As these problems are resolved we plan to conduct bioassays to test the effects of silver and selenium on juvenile crabs.

Petroleum Hydrocarbons

Work continued at the Naval Biosciences Laboratory, University of California, Berkeley, on determinations of petroleum hydrocarbon tissue burdens in Dungeness crabs. Samples of small juvenile crabs from Humboldt Bay and from San Francisco Bay were submitted for analysis. Higher levels of hydrocarbons were found in the small juveniles from Humboldt Bay than in those from San Francisco Bay. This was in contrast to previous work with large juveniles and adults, which showed higher hydrocarbon levels in San Francisco area crabs (Orcutt et al. 1976).

Direct comparisons of crabs of different size within an area are difficult because small juveniles were analyzed as whole organisms whereas the larger crabs were dissected and muscle and hepatopancreas tissues analyzed separately. However, the findings of low levels of hydrocarbons in small San Francisco juveniles and higher levels in large juveniles and adults suggest that San Francisco Bay crabs are acquiring large hydrocarbon burdens while they grow.

Further research is required to identify specific hydrocarbon contaminants and their potential effects on the physiology of the crabs.

Proposals for Additional Research

Early in the program, several areas of research on environmental toxicants were identified which required additional funding, expertise, and facilities beyond those available to the project. The primary concerns were for research on effects of chlorine-treated waste-effluents on juvenile Dungeness crabs, effects of petroleum hydrocarbons on crabs, and toxic trace elements in crab tissues.

Persons and agencies with expertise and facilities in these areas were contacted and various sources of funding were explored. A small amount of contract funds from the Dungeness Crab Research Program provided for the preliminary work on petroleum hydrocarbons reported in the previous section. A contract with the State Water Resources Control Board provided for some preliminary work on toxic trace elements. In cooperation with U.C. Berkeley's Sanitary Engineering Research Laboratory (SERL) we sought outside funding for research on chlorine-treated waste-effluents.

The record crab landings in northern California during the 1975-76 and 1976-77 seasons generated more crab tax funds than anticipated. This made it feasible to consider funding these studies by the Department. In late November 1977, proposals for these studies were approved for Departmental funding for Fiscal Year 1978-79. Although this is rather late in the program, some information should be available for the September 1979 report to the Legislature.

The following studies were approved for Departmental funding:

1. Effects of chlorine-treated waste effluents on juvenile Dungeness crabs.
2. Identification of major petroleum hydrocarbon contaminants in San Francisco area Dungeness crabs.
3. Additional experiments on the effects of toxic trace elements on juvenile Dungeness crabs.

MARINE CULTURE LABORATORY CRAB STUDIES

by

Earl E. Ebert[6/] and Paul N. Reilly[7/]

Major effort at the Marine Culture Laboratory (MCL) continued on development of small-scale, mass-rearing techniques. A satisfactory method to cultivate zoeal stages of crab larvae was developed. The refinement of satisfactory methods for cultivation of crab megalopae and post-larval instars was marginally successful. Limited manpower at critical times precluded the setting up for, and performance of, planned test trials.

Unresolved crab culture problems include occasional fungal infection, zoeal spine breakage, and larval stunting (laboratory cultured megalopae are smaller than those in wild populations).

Culture Systems

The zoeal stage culture system consists of double plastic containers, one enclosed within the other. Larvae are reared in the inner, screened-bottom container, while the outer container maintains water level and passage from the system. Water flows in a circular, downward path through the larval rearing container, and exits through portholes located immediately beneath the screening and around the perimeter of the larvae container. Water exits from the surrounding outer container at the top and bottom through inner connected drain pipes. The larvae container has a capacity of 7.9 liter (2 gal).

Two basic culture methods (communal and compartmented), and three substrates (sand, astroturf, and perforated styrene), were tested with

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megalopae. Communal cultures were sand or astroturf, while compartmented cultures were sand or perforated styrene substrates.

Test Trials

Standard culture techniques were established for zoeal culture experiments, largely based on previous experimentation, then selected parameters were varied and the effect measured. Standard techniques were: (i) one zoea per 10 ml of water volume; (ii) a temperature of 14 C $\pm$ 1 C (57.2 F $\pm$ 1.8 F); (iii) 5 to 10 brine shrimp nauplii per ml of culture volume; (iv) a water flow rate of 0.5 to 0.8 liter (0.5 to 0.9 quart) per min; (v) a photoperiod of 9 hr; and (vi) water filtration of 3 microns.

Variations of the standard culture techniques included: (i) doubling the density to one zoeae per 5 ml; (ii) an elevated temperature culture of 17 C (63 F); (iii) two different water filtration levels (1 micron and 15 microns); and (iv) a continuous 24-hr photoperiod.

A total of nine test trials was completed in duplicate with zoeal stage larvae. The fungus *Lagenidium* sp. appeared in three of nine cultures result-in an infection in the larvae and subsequent mortality. Survival in the fungus infected cultures to the megalopal stage ranged from 0 to 24.8%, and averaged about 12%. Larval survival in non-fungal cultures to the megalopal stage averaged about 40% and ranged from 16.4 to 80.6%.

Larval survival to the megalopal stage in the high density cultures (one per 5 ml) compared favorably with those of standard density (one per 10 ml), in the absence of *Lagenidium* sp., through zoeal stage IV. However, a sharp mortality increase occurred between zoeal stages IV and V.

Best survival to the megalopal stage, averaging 73.8%, occurred at an elevated temperature of 17 C (63 F).

Zoeal stage development rates in the standard temperature cultures were fairly uniform; however, zoeae took significantly less time to achieve the megalopal stage in the elevated temperature culture. Zoeae required from 45 to 49 days, averaging 46, in the standard temperature cultures to reach the megalopal stage. In contrast, they took only 32 days (14 days less) at an elevated temperature to attain the megalopal stage.

All three water filtration levels (1 μm, 3 μm and 15 μm) resulted in fair to good culture success. Larval survival was slightly better in the 1 μm filtered water when compared to the 3 μm filtered water. The 15 μm filtered water could not be compared because other culture parameters (temperature, photoperiod, and culture screen size) differed at this filtration level.

A continuous, 24-hr photoperiod, when compared to a 9-hr photoperiod, disclosed no discernible differences for larval developmental rates, survival, or forage requirements.

The average number of brine shrimp nauplii used per zoea, by stage, was calculated to be: Stage I - 13.0; II - 21.1; III - 30.0; IV - 36.2; and V - 66.0.

Cultured zoeae and megalopae were visibly smaller than their wild population counterparts (Table 6). Measurements were made of laboratory-reared larvae and compared with those of field-captured specimens. A steady decline was noted in the ratio of mean sizes of laboratory-reared to field-captured larvae with each successive stage; megalopae from MCL were only 69 to 75% as large as those from the wild population. In some instances cultured megalopae appeared to be in a weakened condition immediately after

TABLE 6. Sizes of Laboratory-Reared and Field-Captured *Cancer magister* Larvae.

Larval stage	Type of measurement*	Field-captured larvae No. measured	Field-captured larvae Mean (mm)	Field-captured larvae Range (mm)	Laboratory-reared larvae No. measured	Laboratory-reared larvae Mean (mm)	Laboratory-reared larvae Range (mm)	Ratio of means - lab/field
zoea I	A	34	2.05	1.91-2.16	20	2.06	1.96-2.18	1.00
	D	35	0.60	0.56-0.63	20	0.57	0.53-0.59	0.95
zoea II	A	23	2.87	2.67-3.19	20	2.72	2.60-2.84	0.95
	D	28	0.90	0.84-1.00	20	0.81	0.76-0.84	0.90
zoea III	A	9	4.31	3.90-4.61	5	3.84	3.72-3.91	0.89
	D	13	1.22	1.16-1.32	20	1.05	0.96-1.17	0.86
zoea IV	A	7	6.89	6.76-7.06	6	5.44	5.34-5.54	0.79
	D	6	1.71	1.65-1.88	18	1.39	1.29-1.45	0.81
zoea V	A	4	9.69	9.22-10.10	2	6.89	6.86-6.91	0.71
	D	23	2.42	2.28-2.56	8	1.94	1.86-2.01	0.80
megalopa	L	50	6.67	6.01-7.15	8	4.70	4.33-5.00	0.71
	W	50	4.07	3.31-4.70	8	2.82	2.65-3.14	0.69
	D	20	4.11	3.84-4.31	8	3.07	2.70-3.24	0.75

* Definition of measurements: A - distance from tip of dorsal spine to tip of rostral spine; D - distance between outer edges of eyes across the carapace; L - distance from back of carapace (excluding dorsal spine) to tip of rostral spine; W - greatest width of carapace.

achieving this stage. Their survival in the communal cultures was poor overall but was likely a result of several factors that included insufficient manpower for proper experimental set-up and maintenance, inability to control water temperature, and insufficient curing time for the culture tanks prior to their being stocked with megalopae. Results were too incomplete for proper analysis, but further testing is anticipated.

In contrast to the communal culture experiments, results of the compartmented cultures were very encouraging. A total of 216 megalopae were cultured on perforated styrene substrates, and 178 (82.4%) of these survived to the first crab instar. Only 26 megalopae were cultured on sand substrate compartments, but 23 (88.5%) of these survived to the first crab instar.

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REFERENCES

Orcutt, Harold G., Robert N. Tasto, and Paul W. Wild. 1975a. Dungeness crab research program. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. (75-8): 1-35.

Orcutt, Harold G., Robert N. Tasto, Paul W. Wild, Charles W. Haugen, and Patrick C. Collier. 1975b. Dungeness crab research program. Report for the year 1975. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. (75-12): 1-77.

Orcutt, Harold G., Robert N. Tasto, Paul W. Wild, Charles W. Haugen, and Earl E. Ebert. 1976. Dungeness crab research program. Report for the year 1976. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. (76-15): 1-42.